Representation of Arctic mixed-phase clouds in the ECMWF Integrated Forecasting System during MOSAiC

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The Model

The ECMWF Integrated Forecasting System (IFS) is a global **numerical weather prediction** model, which is also used for **climate projections** and the reanalysis **ERA5**. The representation of clouds is important because of their radiative impact, but uncertain (e.g. Morrison et al., 2020).

Cloud processes are parametrised based on grid-box mean quantities with separate prognostic variables for liquid and ice cloud mass (see references for full documentation).

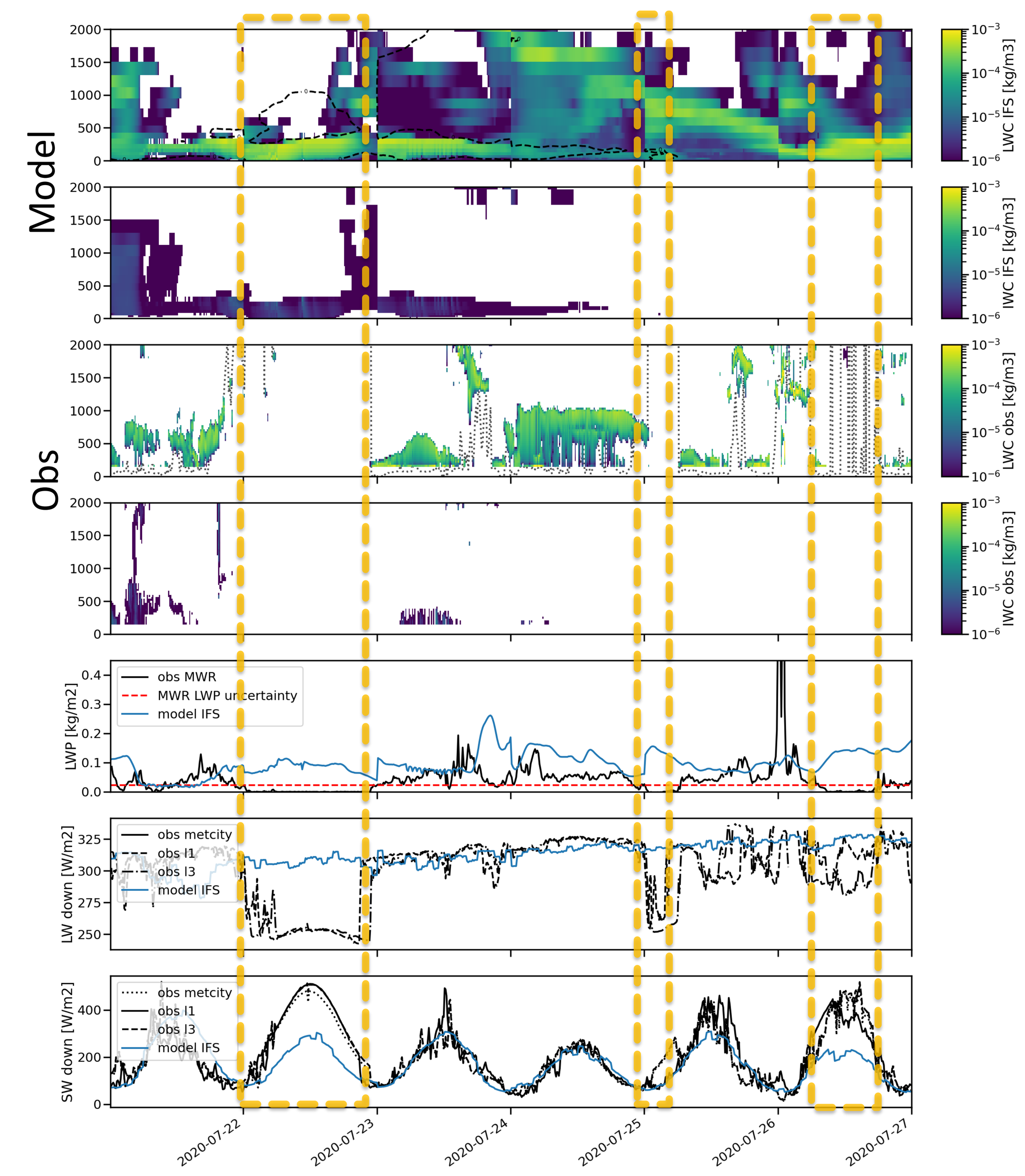
The IFS **Single Column Model (SCM)** simulates one atmospheric column using the same parametrisations as the 3D model.
The column is initialised and forced with profiles and advective tendencies from a 3D model run.

The Observations

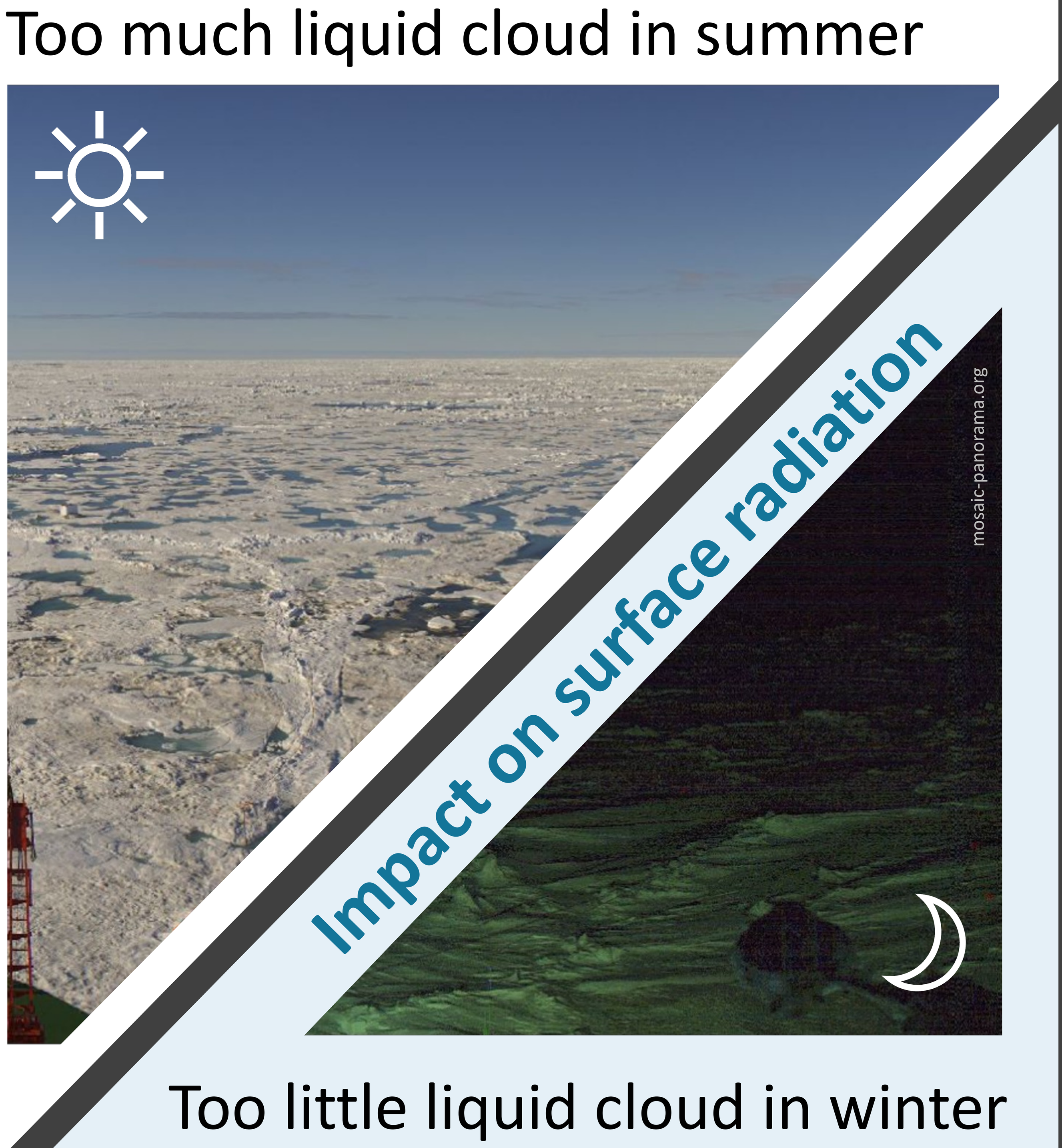
The MOSAiC campaign provides atmospheric observational data from the central Arctic for a **full year** (Shupe et al., 2022). Arctic mixed-phase clouds are common and have a large radiative forcing compared to ice-only clouds (Shupe and Intrieri, 2004).

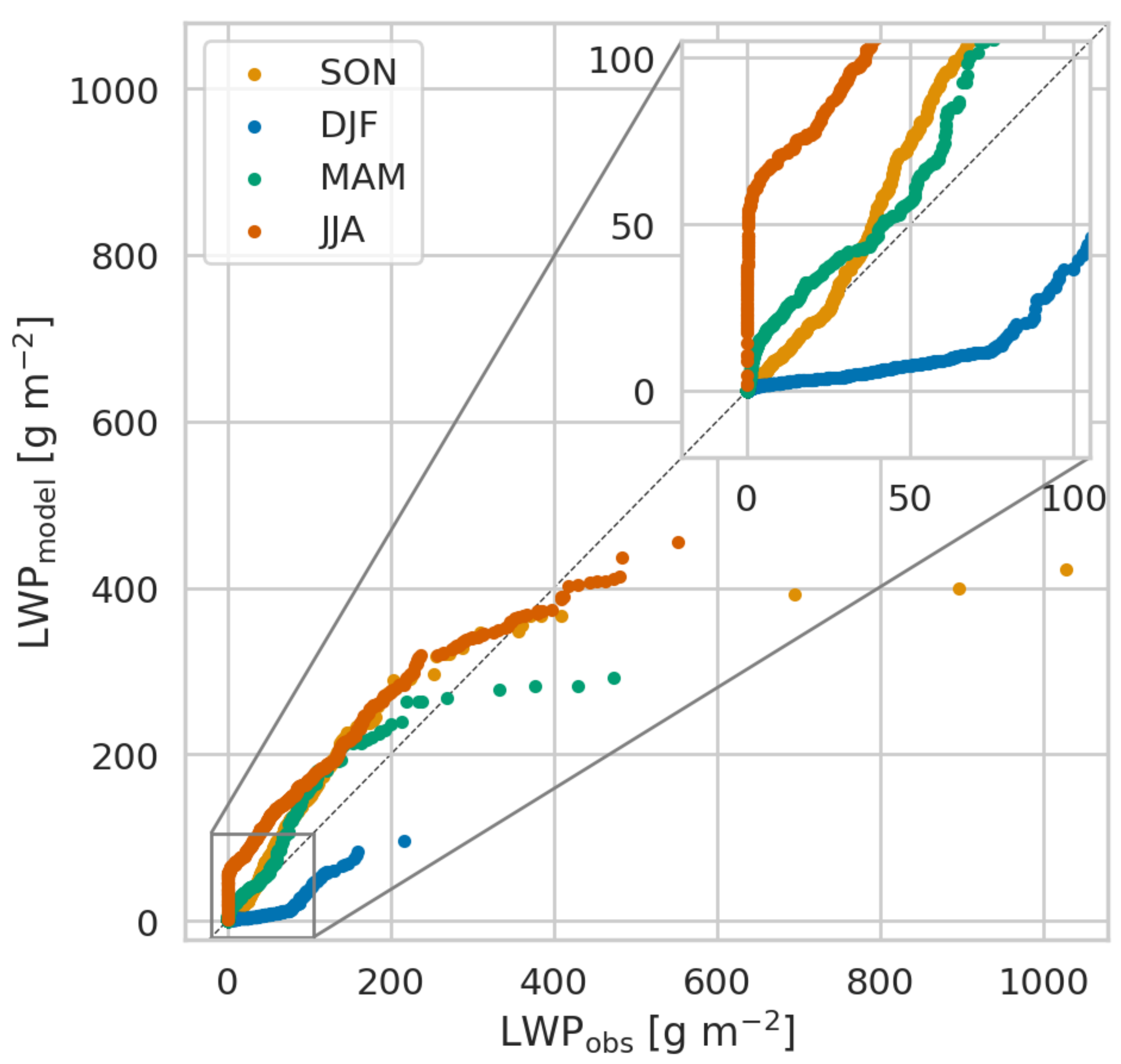
Data used for the evaluation:

Temperature & Moisture profiles	Extended radiosonde profiles Dahlke et al., 2023
LWP, IWV	HATPRO & MiRAC-P MWR Walbröl et al., 2022
Broadband radiation (LW/SW down)	Atmospheric Surface Flux Stations at 4 sites Cox et al., 2023 abcd
Liquid water content, Ice water content	ShupeTurner cloud microphysics product Shupe 2022



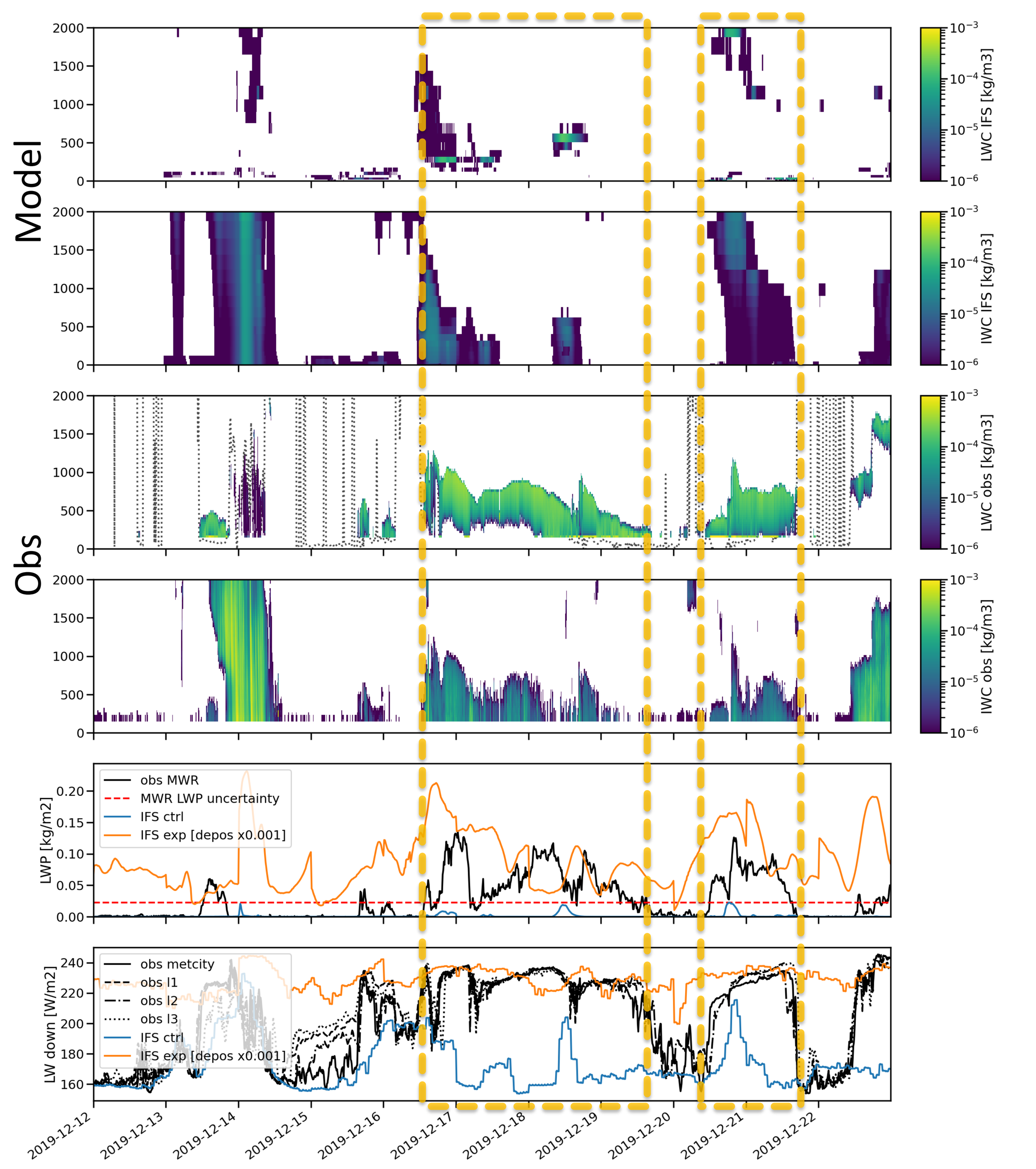
Example case of missed clear-sky periods in July





Quantile-quantile plot of hourly liquid water path (LWP) per season

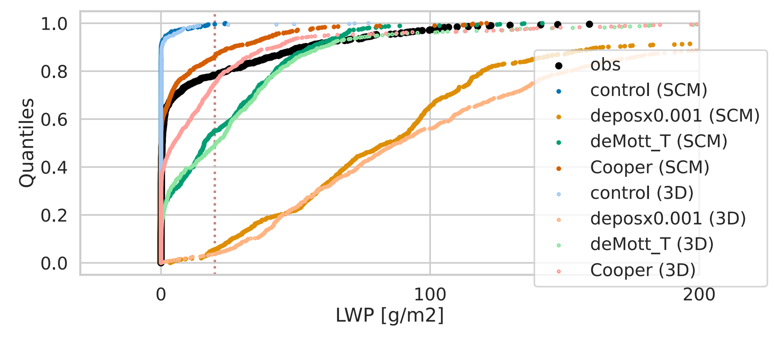
One year in the ice



Example case of missed liquid-containing clouds in December

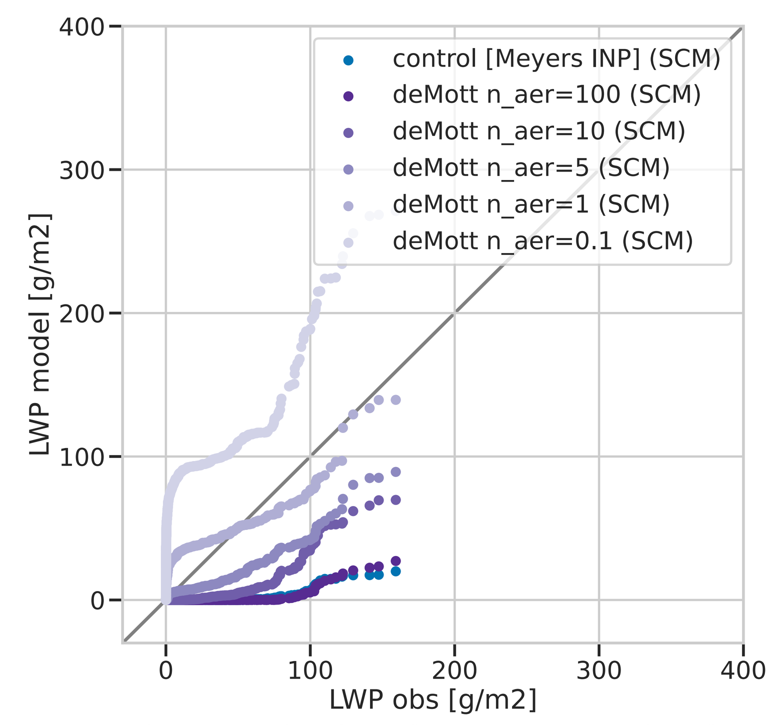
One winter month in a Single Column Model

A **setup test** shows comparable sensitivity in 3D Model and SCM.

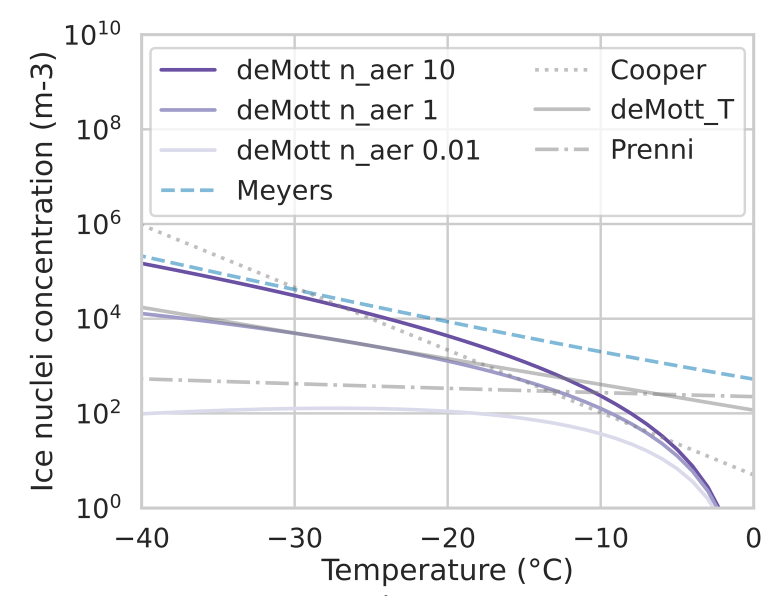


Setup test: LWP quantiles for sensitivity tests in 3D model and SCM for December 2019

The modelled LWP shows a strong **sensitivity** to the parametrisation of the **Wegener-Bergeron-Findeisen (WBF) process** in winter. Using aerosol concentrations in the observed range of 0.1 to 10 cm^{-3} change the LWP distribution from underestimation to overestimation.



Quantile-quantile plot of LWP in December for different aerosol concentrations in the SCM



Parametrisations of ice particle number concentration

Conclusions

- Known regime-dependent biases occur in the IFS during the MOSAiC campaign: underestimation of Arctic winter mixed-phase clouds and miss of summer clear-sky periods – both with clear impact on surface radiation.
- The sensitivity of cloud liquid water to reduced aerosol concentrations in cold temperatures suggests that an aerosol dependence should be included in the WBF parametrisation.
- A WBF parametrisation using aerosol climatology may improve cloud liquid water in Arctic winter without affecting mixed-phase clouds at lower latitudes – a topic for future work.

Open questions

Using a fixed low aerosol concentration tends to result in persistent liquid cloud layers. Do we need to represent **aerosol variability** to capture both cloudy and clear-sky state? Or are other **missing processes** driving the breakup of clouds, maybe similar to the problem in summer?

References

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